

X(16.7) Production in Electron-Positron Collision

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Abstract

The anomaly found in a recent study of excited ^8Be decay to ground state is attributed to an unusual vector gauge boson, the X(16.7). A 17 MeV gauge boson is obviously unexpected and hard to be embedded into the particle zoo of the Standard Model. To confirm this finding, further experimental studies are necessary. In this work, the production of this yet-not-verified new boson in electron-positron collision, for instance at BaBar is evaluated, and the results are encouraging. The data collected at BESIII and BaBar turn out to be enough to perform a decisive analysis and hence give a definite answer to the existence of X(16.7).

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The search of new physics beyond the Standard Model (BSM) is now a major activity for experimental and theoretical physicists. So far, the Standard Model(SM) has achieved a great success in experiencing numerous experimental tests [1]. Up to date, it is well-known that only four kinds of forces have been observed and investigated. Finding out whether there exists a new type of force beyond the known four forms of interactions is a very tempting task. Recently, an extraordinary experimental phenomenon was observed in ${}^8\text{Be}$ nuclear transitions, ${}^8\text{Be}^* \rightarrow {}^8\text{Be} X$, and then followed by the saturating decay $X \rightarrow e^+e^-$ [2]. A significant enhancement relative to the internal pair creation was observed at large angles in the invariant mass distribution of electron-positron pairs production. This observation is hard to be understood within the regime of conventional theory, but could be attributed to a neutral isoscalar particle with mass of 16.7 MeV beyond the Standard model. In the literature, this anomaly has been interpreted as a new vector boson which mediates a weak fifth force beyond the standard model [3], and a so-called realistic model for fifth force is also proposed by Pei-Hong Gu and Xiao-Gang He recently [4]. Scientifically, to investigate further experimentally and get more knowledge of this-yet-not-independently-verified particle is currently the most important task among other studies of this new boson.

In this work, we estimate the production rates of this new boson at electron-positron colliders, that is the X-boson production associated with a photon in e^+e^- collision. The differential cross sections versus the center-of-mass energy, the emitting angle and invariant mass of final electron-positron pairs are calculated. To disentangle the signal from background, we suggest to measure the decay length of X(16.7) in experiment, which are measurable according to our analysis.

As in Ref.[3], we suppose also a 16.7 MeV or so spin-1 Abelian gauge boson exist, which attributes to the the abnormal data observed in the nuclear transition of an excited state to the ground state. This new particle couples to the SM fermions through vector current, the new Lagrangian can be formulated as:

$$\mathcal{L} = -\frac{1}{4}X_{\mu\nu}X^{\mu\nu} + \frac{1}{2}m_X^2 X_\mu X^\mu - \Sigma_f \varepsilon_f e \bar{f} \gamma_\mu f X^\mu . \quad (1)$$

Here, e is the electron charge and ε_f denotes the coupling strength of X to vector current, which for electron is constrained by experimental data to the region of $2 \times 10^{-4} \leq |\varepsilon_e| \leq$

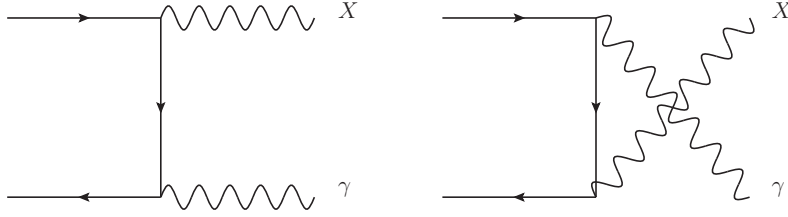


FIG. 1: The leading diagrams that contribute to the X-boson production in electron-positron collision.

1.4×10^{-3} [3].

Since M_X is much lower than the energies of usual electron-positron colliders, its leading production process always associates with another gauge boson radiation, typically a photon, as shown in Figure 1. The differential cross-section of the process in Fig.1 can be readily obtained as:

$$\frac{d\sigma}{d\cos\theta} = \frac{2\pi\varepsilon_e^2\alpha^2(s - m_X^2)}{16s\sqrt{s(s - 4m_e^2)}} \times \left(\frac{32s(s(s^2 + m_X^4 + 4m_e^2(s - 2m_X^2) - 16m_e^4) + \cos^2\theta(4m_e^2 - s)(s(s + 4m_e^2) + m_X^4))}{(s - m_X^2)^2(s + (4m_e^2 - s)\cos^2\theta)} - 16 \right). \quad (2)$$

Here, θ is the emitting angle of photon with respect to the beam axis. Taking $m_e, m_x \rightarrow 0$ and $\varepsilon_e \rightarrow 1$, the differential cross-section turns to

$$\frac{d\sigma}{d\cos\theta} = \frac{2\pi\alpha^2(1 + \cos^2\theta)}{s\sin^2\theta}, \quad (3)$$

which agrees with the well-known result for $e^+e^- \rightarrow 2\gamma$ [5].

With the differential cross section (3), one can get the colliding energy dependence of the cross section. Taking the typical BEPCII colliding energy of 3.1 GeV for instance, since the BESIII detector may cover about 93% of the 4π solid angle, the photon emitting angle θ is restricted to $|\cos\theta| < 0.93$. In the numerical evaluation, we take the fine structure constant α to be $1/137$, and ε_e to be 1×10^{-3} . The variation of the cross section on center-of-mass system(CMS) energy squared is shown in Figure 2, in which

one may notice that the cross section drops very quickly with the increase of CMS energy.

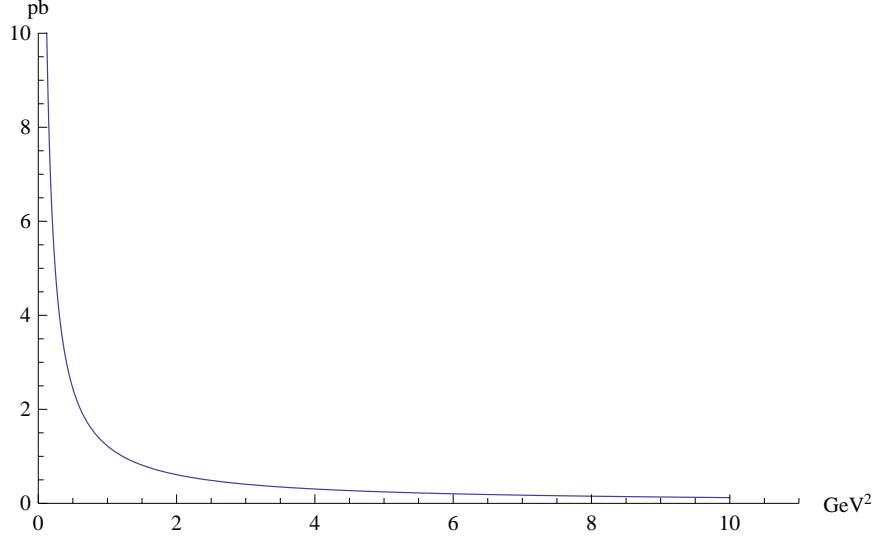


FIG. 2: The cross section as a function of the CMS energy squared s .

At the CMS energy 3.1 GeV, the differential cross section varying with respect to $\cos \theta$ is shown in Figure 3. One may notice from the figure that the main contribution comes from the region where $\cos \theta$ is large, i.e. the small emitting angle θ . For $|\cos \theta| < 0.93$, the BESIII detector condition, and $2 \times 10^{-4} \leq |\varepsilon_e| \leq 1.4 \times 10^{-3}$ [3], we find the cross section lies in $2.59 \sim 0.127$ pb. To the current highest BEPCII luminosity of $1 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$, there will be about $82 \sim 4003$ X bosons to be produced per year and more in yet collected data. At B-factories, like BaBar, with CMS energy 10.6 GeV, the cross section is about $0.22 \sim 10.85$ fb. With the data 514fb^{-1} collected at BaBar [6], there should be $113 \sim 5577$ X bosons produced.

It seems that the couplings of X boson to neutrinos may be neglected in comparison to its coupling to electron [3]. That means the X boson decays to electron-positron pair in saturation. The X-boson decay width reads as:

$$\Gamma(X \rightarrow e^+e^-) = \varepsilon_e^2 \alpha \frac{m_X^2 + 2m_e^2}{3m_X} \sqrt{1 - \frac{4m_e^2}{m_X^2}}. \quad (4)$$

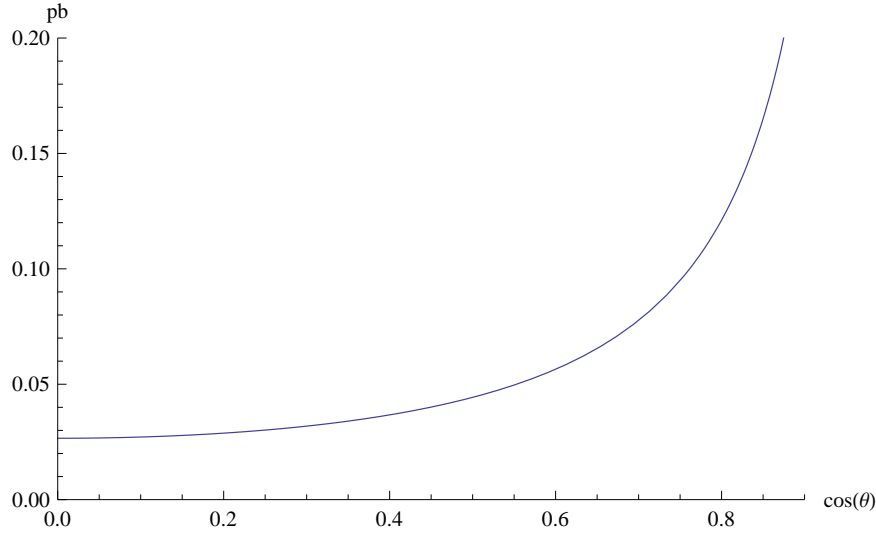


FIG. 3: The differential cross section varies with emitting angle θ at $\sqrt{s} = 3.1$ GeV.

Adopting the magnitude of ε_e given in above, the X-boson decay width goes as $\Gamma = 1.63 \times 10^{-12} \sim 7.96 \times 10^{-11}$ GeV, which corresponds to the lifetime $\tau = 8.26 \times 10^{-15} \sim 4.05 \times 10^{-13}$ s at the X-boson rest frame. After performing the Lorentz boost the X-boson decay length in experiment frame can be obtained. The velocity of X boson and the energy of the emitting photon reads as $v = \frac{E_0}{\sqrt{E_0^2 + m_X^2}}$ and $E_0 = \frac{s - m_X^2}{2\sqrt{s}}$, respectively. Hence, the decay length of X boson in experiment frame at the CMS energy of 3.1 GeV is

$$L = \frac{4.51 \times 10^{-10}}{\varepsilon_e^2} \text{m} , \quad (5)$$

which numerically means $0.23 \text{ mm} < L < 11.3 \text{ mm}$, and is measurable at BESIII. At B-factories, whose CMS energy is about 10.6 GeV, the decay length can reach $0.79 \text{ mm} \sim 38.55 \text{ mm}$; while at CLOE, whose CMS energy is 1.0195 GeV, the decay length of X boson is merely $0.076 \text{ mm} \sim 3.71 \text{ mm}$. Evidently, it is more attainable to measure the decay length of X boson at BaBar, Belle or BESIII than at CLOE. The measurement of the decay length is meaningful not only for the aim of disentangle the signal from background, but also for the determination of parameter ε_e .

Since the X-boson decays to electron-positron pair in saturation, the dominant background originates from the $e^+e^- \rightarrow e^+e^-\gamma$ scattering process. To evaluate the invariant-

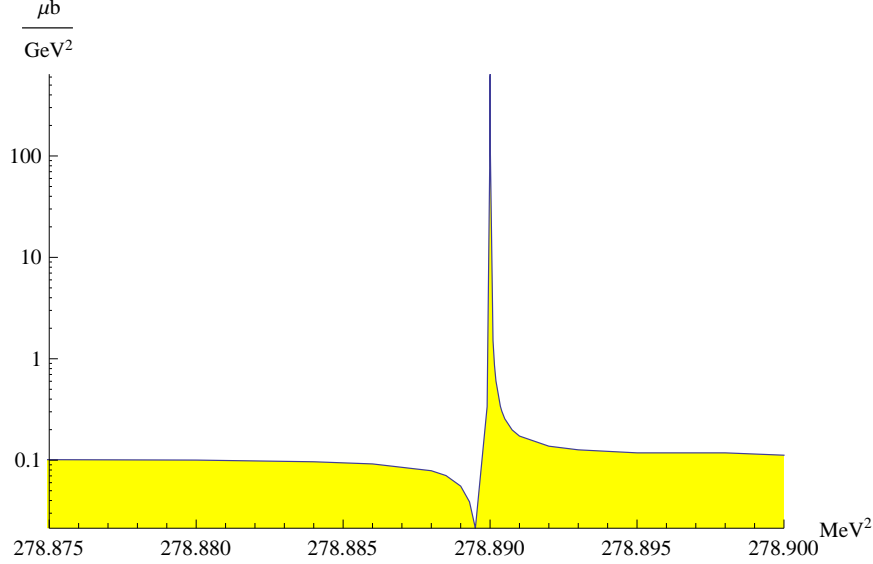


FIG. 4: The differential cross section varies with the invariant mass of e^+e^- in final state.

mass distribution of e^+e^- in final state, we consider diagrams that contain both γ and X as inner propagators, and neglect the contribution from Z boson. There are 16 Feynman diagrams should be taken into account. In Figure 4 we show the invariant-mass distribution of e^+e^- in final state for the differential cross section. From the figure it is notable that there exists a rather narrow peak around the squared mass of X boson, i.e. $(16.7\text{MeV})^2$. Which tells that a precise measurement on the invariant mass of final state electron-positron pair will greatly suppress the background and hence help the discovery of this new boson.

Note that the BaBar and KLOE experiments had ever searched the darkphoton before [6, 7]. However, by then the the mass range in BaBar search is in between $20\text{ MeV} \sim 10.2\text{ GeV}$, which just overshoot the X boson at 16.7 MeV . The CLOE experiment did not find clear signature of darkphoton, whereas it constrained the parameter ε_e to be $|\varepsilon_e| \leq 2 \times 10^{-3}$, which is in accordance with what we employ in this work.

In summary, inspired by the 6.8σ anomaly in ^8Be nuclear transitions experiment and the interpretation of Ref.[3], we investigate the possibility of detecting/searching

this yet-not-verified gauge boson $X(16.7)$ at e^+e^- colliders. It turns out that at BESIII there should be about $82 \sim 4003$ X boson to be produced each year, and the numbers at B-factories are even higher, e.g. $113 \sim 5577$ at BaBar with integrated luminosity of $514fb^{-1}$. With a precise measurement of the invariant-mass distribution of the final state e^+e^- near the squared mass of X boson, and its decay length to further suppress the background, it is feasible for BESIII, BaBar, or SuperKEKB experiment to perform a decisive analysis and hence gives a definite answer to the existence of X boson. Note, in other types of high energy experiments, such as the ep collision at DarkLight [8] and pp collision at LHCb [9], the X boson may also be detectable and deserve further studies.

Finally, in a recent paper [4], Pei-Hong Gu and Xiao-Gang He proposed a so-called realistic model for a fifth force, by which the cross section of $e^+e^- \rightarrow \gamma X$ tends to be less than 10^{-2} fb, much smaller than our estimation, and hence the search of X boson at electron-positron colliders may be also helpful to distinguish different kinds of models.

Acknowledgments

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- [1] K. Olive, *et al.*, Particle Data Group, Chin. Phys. C38, 090001(2014).
- [2] A. Krasznahorkay *et al.*, Phys. Rev. Lett. **116**, 042501(2016).
- [3] J. L. Feng, B. Fornal, I. Galon, S. Gardner, J. Smolinsky, T. M. P. Tait, and P. Tanedo. arXiv:1604.07411.
- [4] Pei-Hong Gu and Xiao-Gang He, arXiv:1606.05171.
- [5] M. E. Peskin and D. V. Schroeder, *An Introduction to Quantum Field Theory*, (Westview 1995).
- [6] J. P. Lees *et al.*, Phys. Rev. Lett. **113**, 201801(2014).
- [7] A. Anastasi *et al.*, Phys. Lett. B 750, 633(2015).
- [8] J. Balewski *et al.*, arXiv:1412.4717.
- [9] P. Ilten, J. Thaler, M. Williams, and W. Xue, Phys. Rev. **D 92**, 115017(2015).